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Relationship of Passive Hip Range of Motion to Countermovement Jump Height and Peak Power Output in Young Adults

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RELATIONSHIP OF PASSIVE HIP RANGE OF MOTION TO
COUNTERMOVEMENT JUMP HEIGHT AND PEAK POWER OUTPUT IN YOUNG
ADULTS

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ABSTRACT

Purpose: The purpose of this study was to examine passive hip range of motion (ROM) and how it relates to countermovement jump height (CMJH) and peak power output (PPO). **Methods:** Twenty subjects (10 males, 10 females), 19-31 years of age (23.5 ± 3.0) participated in this study. Height (170.3 ± 6.9 cm), weight (65.8 ± 10.5 kg) and body fat ($15.6 \pm 6.9\%$, BodPod) were measured. Males with body fat greater than 17.5% and females greater than 27.5% were excluded from the study since jumping ability is limited by body fat. Power athletes were excluded from the study due to their likely jump training. Four passive hip ROMs were measured: flexion, extension, internal rotation (IR) and external rotation (ER). CMJH was measured using a Vertec vertical jump system. PPO was calculated using the Harman equation and then normalized for lean body mass (LBM). Subjects were categorized into groups for low, average and high ROM; those within one standard deviation (SD) of the mean were categorized into the average group; those below one SD of the mean were categorized into the low group; those above one SD of the mean were categorized into the high group. A Pearson correlation was used to determine the relationship between CMJH and PPO to hip ROMs. A one-way ANOVA was used to compare low, average and high ROM groups for CMJH and PPO. **Results:** There were significant ($p < 0.05$) negative correlations between hip flexion, extension and IR with CMJH ($r = -0.67, -0.71, -0.64$ respectively). While hip

ER did not relate significantly ($p \geq 0.05$) to CMJH ($r = 0.33$), there was a significant relationship ($p < 0.05$) with PPO ($r = 0.52$). There were no significant ($p \geq 0.05$) differences in CMJH and PPO when low, average and high ROM groups were compared.

Conclusion: Hip extension was associated with higher CMJH, while hip flexion and internal rotation associated with lower CMJH. Only hip external rotation correlated with PPO with a greater ROM associated with greater PPO. There is, however, no optimal ROM that relates to maximum CMJH or PPO. Flexibility should not be neglected however, as this may alter the alignment of joints and resting muscle length.

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CHAPTER I

INTRODUCTION

Introduction

Power is necessary for athletes to perform at an elite level. Elite athletes have significantly greater lower body power when compared to non-elite athletes (3,8,18). Lower body power is correlated to an improved performance in varying aspects or positions of sport (9,16,18). With the importance of power for athletic performance, it is important to understand what factors play a role in power development. One indirect method that has been developed to measure lower body power is the vertical jump test (4,8,17,23,26,30).

Specific body movements, such as a countermovement jump (CMJ), require the body to go through a predetermined movement pattern (20,22). Studies have been conducted on how various anthropometric and functional factors play a positive or negative role in predicting vertical jump height (1,10,11,13). However, there have been no studies conducted on the role of passive hip range of motion (ROM) to CMJ performance and peak power output (PPO).

Significance of Study

This study will help shed light on the potential relationship between hip ROM and CMJ height (CMJH) and PPO. There have been many issues associated with limited hip mobility (10,11,14). However, no research has been conducted on how passive ROM plays a role in power development. The information obtained may help in designing programs for individuals to allow them to move and perform tasks more efficiently.

If it is determined that there is significant relationship between hip ROM and vertical jump height and power output, this will allow strength and conditioning professionals to focus on optimal ROM for training their clients. If an individual has too small of a ROM, it may not allow for complete power development and an optimal jump height. Likewise, if an individual's ROM is too great it may also detract from their ability to develop maximal power. Coaches and trainers will know whether or not athletes need to improve ROM or if they should place less of a focus on ROM training.

Purpose

The purpose of this study was to determine the relationship of passive hip ROM to countermovement jump height and peak power output. If hip ROM is significantly related to PPO, improvements can be made in training programs for athletes.

Hypotheses

The following hypotheses were tested in this study:

1. There will be a significant relationship between passive hip ROM, vertical jump height, and peak power output when normalized for lean body mass.
2. Subjects with an average range of motion will perform better than those with either a high or low hip range of motion.

CHAPTER II

LITERATURE REVIEW

Literature Review

Optimal movement is achieved when that movement occurs without pain or discomfort and involves proper joint alignment, muscle coordination and posture (10). Cibulka and Threlkeld-Watkins (10) reported a case study of a 15-year old female athlete who suffered from anterior right knee pain during sport activities such as running and jumping. The subject did not mention any previous injury that would be the cause of this pain. Upon examination, it was found that the pain was caused by joint misalignment and muscle weakness associated with the right hip joint (10). By implementing a program that included stretching and muscle strengthening, right hip ROM was improved to a level similar to that of the left hip (10). Upon this improvement, there was a noted decrease in overall pain (10). However, running and jumping performance were not measured after the intervention.

As stated earlier, there is a difference in power capabilities between elite and non-elite athletes (3,8,18). Palmer et al. (28) examined the effect of muscular stiffness on CMJ height and PPO in female NCAA Division I athletes (n=10) and non-athletes (n=11). Participants had

muscle stiffness measured through a passive straight leg test (28) to determine a relationship. Although the athletes exhibited a higher CMJH and PPO, there was no difference in passive hip ROM (28). Based on the results, the authors concluded that passive muscle stiffness was an effective means of discriminating athletes from non-athletes (28). The athletes' training also may have played a role in their CMJ height and PPO due to the use of plyometrics and resistance training protocols (28).

Out of 17,013 male and female Canadians surveyed between the ages of 18 and 90 years, 7,339 self-reported spending over half the day in a seated position (19). Sitting can lead to many health issues and is a major sign of inactivity (19), and is correlated with potential joint dysfunction. In the seated position, the iliopsoas muscle is in a contracted state pulling on the pelvis and causing an anterior tilt (12). When the hip joint is placed in this position, the muscles on the posterior portion of the hips are stretched (12). This includes the gluteus maximus, gluteus medius, and hamstring muscle groups. Hip mobility can be compromised by remaining in a seated position for extended periods of time (12). Changes in muscle length can be detrimental to performance (4). Muscles develop power by creating cross bridges between actin and myosin filaments, which requires the muscles to be at the proper length and tension (4). When taking into account the potential limitation of muscles to lengthen properly, this may have an effect on the stretch shortening cycle (SSC). The CMJ takes into account the SSC that occurs in the muscles of the legs as they go through the quick change between the eccentric and concentric phases of the movement (4,21,22). Altering the SSC may therefore detract from power generation and CMJ height.

Altered joint positioning at the hip has been associated with patellofemoral joint pain (10) and low back pain (15). Changes in hip position leads to a direct change in the movement of the

femoral head of the hip joint (10,14,15). Moreside and McGill (25) improved passive ROM at the hip to test its role in various functional movements that included active hip extension, flexion, internal rotation and external rotation in upright standing, lunging, standing “twist and reach” and exercising on an elliptical machine. Out of 250 males, ages 19-30 years, that were initially screened for hip ROM, the 24 with the smallest ROM were selected to participate and randomly assigned to four separate groups: Group 1 received hip stretching only; Group 2 received hip stretching and hip/spine disassociation exercises; Group 3 received core endurance and hip/spine disassociation exercises; and Group 4 was a control group that did not participate in any intervention (25). After the 6-week protocol, Groups 1, 2, and 3 showed varied levels of improvement in hip extension and lumbar extension, whereas Group 4 did not show any improvement (25). However, the improved passive ROM did not lead to an increase in ROM during any of the movements tested, which included active hip extension while upright standing, lunging, a standing twist and reach maneuver and exercising on an elliptical trainer (25). CMJ was not one of the movements tested.

Muscular strength, specifically the squat one repetition maximum (1-RM), has been positively correlated to vertical jump height (25 – 27). Based on this, many athletes include squats and similar movement patterns in their vertical jump training programs (2,9,25 – 27). Baker (2) suggested some strength-training methods of improving CMJ including weighted squats. Hip mobility has been determined to be a factor in proper squat form (20,29,30) and this suggests there should also be a link between hip mobility and vertical jump performance. Hip mobility can alter squat patterns and the ability to achieve full depth properly (20,30). Measuring passive ROM and also vertical jump height can be used to determine if there is a relationship between the two.

Power is defined as (Force x Distance)/Time (4). Various methods have been developed to measure lower body power output including video motion analysis, jump and reach methods, and contact mats (21). A three-camera motion analysis system has been indicated as the “gold standard” for measuring vertical jump height (21). According to the National Strength and Conditioning Association (NSCA), the vertical jump test can be used to determine power of the lower body (4). One device that is used frequently to determine vertical jump height is the Vertec vertical jump measuring system (4,21). Leard et al. (21) enlisted 40 college students (26 females, 14 males), mean age of 20.7 years, who were taught to properly execute a CMJ (21). A jump mat was placed under a Vertec with the three-camera motion analysis system set up to monitor for simultaneous measurement using all three methods (21). Subjects then performed a CMJ and had their jump height and power output compared between the three methods. A Pearson correlation between the Vertec jump system, the Just Jump contact mat, and the three-camera motion analysis system found the Vertec to be an acceptable form of measurement ($r = .906$)(21). This high correlation indicates the Vertec can be used to measure vertical jump height with a high level of confidence.

Different pelvic tilts have a different effect on the muscles surrounding the hip. When the pelvis tilts anteriorly, the gluteus and hamstrings muscles are stretched constantly causing them to lengthen (12). In contrast, however, when there is a posterior pelvic tilt, the gluteus and hamstring muscles are in a constantly contracted state not allowing them to reach their proper length (12). When muscles are in their normal resting state, there are an optimal number of potential cross-bridge sites available to allow for greater force production (4). In either the contracted or stretched state, the muscle loses its ability to produce maximal force due to the change in arrangement between actin and myosin filaments (4). This raises the question of what

is the optimal ROM at the hip joint to allow for muscles to be at their optimal length and produce the greatest power output.

The muscles of the anterior and posterior hip work in an antagonist vs. agonist fashion. Wakefield and Cottrell (33) examined the effect of static stretching the hip flexors and hip extensors to determine their relationship to vertical jump height. Passive hip extension ROM was measured prior to any testing. Each subject completed one of three interventions: no stretch, hip flexor stretch and hip extensor stretch. There was a significant increase in hip extension ROM after the hip flexor stretch when compared to the no stretch and hip extensor stretch protocols (33). There was also a significant increase in vertical jump height for the hip flexor stretch (33). The authors suggest that static stretching of the hip flexors may enhance vertical jump performance independent of changes in passive compliance of the muscles (33).

Discrepancies between right and left limb have been related to broad jump lengths in females (5). Females and males, ages 18-26 years, had their passive hip flexion and IR measured separately on each leg. They then performed both a vertical jump test and broad jump test. A difference of $0.62^{\circ} \pm 4.97^{\circ}$ in the female sample had a significant correlation ($r = -0.69$) with broad jump length (5). There was, however, no significant relationship between either males or females with vertical jump height and limb ROM discrepancies (5).

Normative ROM at the hip joint was evaluated by Moreside and McGill (24) in 77 men, mean age of 22.8 years, where ROM was measured using both a Vicon 3D motion capture system as well as a goniometer. Participants were measured while performing multiple movements and in multiple planes. A Modified Thomas Test (Appendix A, 1) was used to measure supine hip extension (24). Subjects were asked to lie on an examination table with one leg passively extended off the edge of the table while the other leg was actively flexed at the knee and hip

joint. The researcher performing the test actively controlled any rotation or ab/adduction of the hip or legs. Hip rotation was then measured in three positions. While lying in a prone position, subjects were instructed to place both knees on the examination table with their knees flexed to a 90° angle and the soles of the feet facing the ceiling. This “bias” position was used as the reference point for the other measurements and the score was subtracted to account for error (24). The second measurement, internal rotation (IR), was taken on both legs simultaneously by passively allowing the feet to fall away from the midline of the body (Appendix A, 2a) while maintaining a 90° angle at the knee joint (Appendix A, 2b). Lastly, external rotation (ER) was measured by allowing one leg at a time to come down laterally with the foot and shin crossing over the midline of the body (Appendix A, 2c). From the data compiled, percentile rankings were created. Of the 77 total participants, a subgroup of 22 had their hip ROM measured using a goniometer (24). When compared to the Vicon 3D motion capture system method, the goniometer was found to have r^2 values of 0.88 for hip extension, 0.95 for internal rotation, 0.92 for external rotation and 0.96 for total rotation (24). This shows that the goniometer is a valid tool for measuring passive hip ROM.

The one ROM that was not measured by Moreside and McGill was hip flexion. Starkey et al. (31) suggest a method of measuring passive hip ROM (Appendix A, 3). Subjects lie flat on their back with both legs fully extended. While keeping the opposite leg flat on the table, one researcher flexes the leg at the hip while keeping the knee fully extended (31). While flexing the hip, the researcher applies slight pressure to the posterior distal femur (31). From here the fulcrum of the goniometer is placed over the greater trochanter with the movement arm aligned over the femur and the stationary arm aligned with the midline of the pelvis (31).

Although normative values were given for male ROM in the specific tests done by Moreside and McGill (24), there are a wide variety of normative values that can be found. For example, Socie et. al. (32) found an average ROM for passive hip flexion to be 133.8° for males and 130.4° for females ages 20 to 44. It was not, however, described in what manner ROM was tested and what criteria was used to determine end ROM for the test (32).

In addition to measuring CMJ height, it is important to determine power output from jump height. Harman et al. (17) derived equations that could accurately be used to determine both peak ($r = 0.88$; $r^2 = 0.77$) and average ($r = 0.73$; $r^2 = 0.53$) power output from CMJ height. The Lewis formula had been used previously as a means to measure power output, although there was no scientific support for it (17). The Lewis Formula was found to have underestimated peak power by 70.1 percent (17). To develop a better equation, Harman et al. (17) conducted a study using a force plate and a jump and reach test. Seventeen males, average age of 28.5 (± 6.9) years, height of 179 (± 5.4) cm and weight of 74.7 (± 7.7) kg participated in the study. The following equation was found to have a 0.88 correlation for estimation of peak power output:

Peak Power Output (W) (± 603 W) =

$$61.9 \times \text{Jump Height (cm)} + 36 \times \text{body mass (kg)} + 1,822$$

(17)

This equation gives a rather accurate estimation of PPO that can be used with confidence ($r^2 = 0.77$) when compared to the Lewis Formula (17). This allows power output to also be calculated and correlated to hip ROM.

CHAPTER III

METHODS

Research Design

This study was correlational in nature assessing the relationship between passive hip range of motion, the independent variable, and countermovement jump height and peak power output, the dependent variables.

Subjects

Participants were recruited from Cleveland State University and the surrounding community. Flyers and word of mouth were the two main modes of recruitment. Recreationally active (150 to 300 minutes of activity per week) subjects (10 male, 10 female; age 18-35 years) were recruited. Those who participated in competitive sports that are explosive in nature and utilize jumping were excluded due to their jump likely being greater. Since jumping ability is limited by body fat (1,13), percent fat was also used as an exclusionary criterion for participation. Males with a body fat percentage greater than 17% (average for non-athletic males), and females with body fat percentage greater than 27% (average for non-athletic females) were excluded. An

AHA/ACSM Screening Questionnaire (Appendix B) was used to exclude participants at high risk of cardiovascular or musculoskeletal complications while performing physical activity.

Procedures

After signing an informed consent (Appendix C) approved by the IRB (Appendix D), height, weight and body composition (BodPod) were obtained. Body mass was used to calculate peak power output (PPO) using the equation developed by Harman et al. (17). To ensure the accuracy of the BodPod, subjects were instructed to refrain from eating or drinking at least four hours prior to testing. In addition, they were told not to exercise during the day prior to testing. Body fat percentage was used to exclude over-fat subjects as previously described, as well as to normalize PPO for lean body mass (LBM).

Prior to ROM testing, subjects warmed-up on an exercise bike for five minutes at 100 Watts to warm-up the muscles of the lower body. All measurements were taken using a goniometer in a fashion similar to that of Moreside and McGill (24), except hip flexion, which was assessed as described by Starkey et al. (31). Two testers conducted all ROMs to allow one tester to operate the goniometer and one tester to maintain the subject's proper body position. All subjects had their ROM passively assessed by the same testers to rule out any inter-tester variability (6,7,24).

The first ROM measurement taken was hip flexion. Subjects lay in a supine position with both legs on the examination table. As described by Starkey et al. (31), one researcher passively flexed the hip of the tested leg while keeping the opposite leg flat on the table. When the researchers recognized a rotation of the pelvis as the limb was flexed, this indicated an end ROM (31) and the measurement was taken (Appendix A, 3). This was repeated three times on each limb with the average of the three measurements used.

The next ROM measurement was hip extension. Subjects lay in a supine position on an examination table. The body was positioned so that the legs were hanging off the table at mid-thigh level. Moreside and McGill (24) noticed during testing of their first few subjects, there was an abnormal tilt of the pelvis and lumbar spine, which altered the overall validity of the test. To reduce this excess lordosis from occurring, a blood pressure cuff was inflated to 60 mmHg and placed under the small of the back (24). As the limb was lowered, any changes in the pressure of the cuff were an indication of alterations in spine and hip alignment (24). The authors felt that this modification added to the accuracy of the measurement while maintaining a neutral spinal and pelvic alignment (24). Subjects were then passively put in a Modified Thomas Test position (Appendix A, 1) with one leg flexed at the hip and knee joint and the other hanging off the edge of the table. To prevent any unwanted internal or external rotation, the researcher gently held the legs in a neutral position with the toes pointing directly towards the ceiling. From this position, the leg being tested was allowed to passively drop towards the examination table. Once the subject could extend no further, or there was a marked change in pressure of the blood pressure cuff, the researcher took a goniometer measurement at the hip joint at maximum extension. Measurements were taken three times on each side. The average of these three measurements were used.

Following hip extension measurements, the subject assumed a prone position for internal and external rotation hip ROM testing (Appendix A, 2). The initial position for internal rotation requires participants to lie with their upper thighs flat on the table and knees flexed at 90° (Appendix A, 2a). This start position was used as the 0° point from which subsequent measurements were used. Internal rotation was measured by having the subjects slowly allowing their feet to fall out towards either side (Appendix A, 2b). To prevent the opposite limb from

having an effect on the limb being tested, one researcher stabilized the untested limb. This was repeated three times on each limb with the average of the three measurements used.

The final measurement was external rotation and was measured from a similar starting position as internal rotation hip ROM, but only had one leg flexed at the knee (Appendix A, 2c). Rather than having the legs move out to the sides, one leg at a time was moved across the sagittal plane of the body. The ipsilateral portion of the pelvis of the leg being measured was lightly held down by the researcher to prevent any pelvic rotation (24). A goniometer was used for all measurements in a similar fashion, as described previously, with three measurements taken and the average recorded.

Once all ROM measurements were taken, subjects had their jump height measured. Due to the nature of this test and its use of the muscles of the lower body, subjects were asked to refrain from any heavy lower body lifting for the 72 hours prior to testing. Subjects performed a countermovement jump (CMJ) on a Vertec Jump System (Power Systems, Inc., Knoxville, TN). Proper CMJ form is shown in the images found in Appendix E. Subjects started in a normal standing position with their feet approximately hip width apart. This is the start position. The next step is the countermovement phase. Subjects flexed their hips and knees to a half squat position while keeping their back flat and chest slightly up. Once they reached the bottom position, the subject jumped straight up and reached for the vanes on the Vertec (Appendix F) with their dominant hand towards the vanes.

To measure the initial reach, subjects stood one step from the Vertec with their dominant hand extended overhead towards the Vertec. The Vertec was set to a height that the subject was capable of reaching using the numbers listed on the base pole of the Vertec. The subject then walked through the Vertec to find their reach height. The bottom vane corresponded to the

number listed on the Vertec. Each vane reached on the walk-through counted as ½ inch from the bottom vane. Based on this initial reach, the Vertec was adjusted according to the subject's previous jumping ability. The new height shown on the base pole was the new height of the lowest vane. From this point, every vane that was reached during a jump counted as a ½ (half) inch in total jump height. Subjects were given three attempts to reach a maximum vertical jump. The vanes were not reset so that the highest jump could be recorded if it came on the first or second jump. If subjects jumped higher than the top vane, then the entire Vertec was reset, and raised a total of 12 inches, and they were allowed to jump again. If on the third jump attempt there was clear evidence that the subject could still reach well above the top vane, they were allowed a fourth and final jump.

Once CMJ had been measured, peak power output was calculated using the following equation developed by Harman et al. (17):

Peak Power Output (PPO) (W) (± 603 W) =

$$61.9 \times \text{Jump Height (cm)} + 36 \times \text{Body Mass (kg)} + 1,822$$

With differences in muscle mass between males and females (4), PPO was corrected for LBM, which was obtained from the BodPod results. Lean body mass was then used to correct power output:

$$\text{W/kg LBM} = \text{PPO (W)} / \text{LBM (kg)}$$

Since no norms for hip ROM were found in the literature, subjects were categorized in low, average and high groups based on standard deviations (SD) of the sample. The mean for each ROM was found and one SD in either direction was used to classify the average group. If a value was below one SD, it was categorized in the low group, while a value above one SD was categorized in the high group.

Data Analysis

A Pearson correlation was used to determine the relationship between the independent variables, passive hip ROMs, and the dependent variables, CMJH and PPO. Independent T-tests were run for gender and the independent and dependent variables. A one-way ANOVA was used to assess differences between CMJ and PPO in low, average and high ROM groups. SPSS (version 22.0) was used for all analyses with 0.05 used as the level of significance.

CHAPTER IV
RESULTS & DISCUSSION

Results

Table 1 presents the descriptive characteristics of the participants of this study. An independent T-test showed that males were significantly ($p < 0.05$) taller, heavier and leaner than females

Table 1. Characteristics of participants (Mean \pm SD).

Gender	Male (n=10)	Female (n=10)	Combined (n=20)
Age (years)	24.2 \pm 2.0	22.8 \pm 3.7	23.5 \pm 3.0
Height (cm)*	175.2 \pm 5.7	165.3 \pm 3.7	170.3 \pm 6.9
Weight (kg)*	72.6 \pm 9.8	59.0 \pm 6.1	65.8 \pm 10.5
Percent Body Fat (%)*	10.8 \pm 4.7	20.4 \pm 5.3	15.6 \pm 6.9

Table 2 shows the passive hip ROMS as well as CMJH and PPO. Both limbs were averaged for each subject and then means obtained for the entire sample, as well as for each gender. An independent T-test showed that females had a significantly ($p < 0.05$) greater hip flexion and internal rotation, while males had significantly ($p < 0.05$) greater hip extension and countermovement jump height (CMJH). Hip external rotation and PPO (corrected for lean body mass (LBM)) did not significantly ($p \geq 0.05$) differ between males and females.

Table 2. Passive hip ROM (right and left legs combined), CMJH, and PPO (Mean \pm SD).

Gender	Male (n=10)	Female (n=10)	Combined (n=20)
Hip Flexion ($^{\circ}$)*	31.2 \pm 5.0	50.0 \pm 11.5	40.6 \pm 12.9
Hip Extension ($^{\circ}$)**	-1.9 \pm 7.1	5.1 \pm 6.2	1.6 \pm 7.4
Hip Internal Rotation ($^{\circ}$)*	30.9 \pm 5.0	42.0 \pm 6.4	36.4 \pm 8.0
Hip External Rotation ($^{\circ}$)	32.0 \pm 11.8	29.5 \pm 7.2	30.7 \pm 9.6
Countermovement Jump Height (cm)*	63.0 \pm 9.3	39.7 \pm 6.8	51.3 \pm 14.4
Peak Power Output per kg LBM \pm 603 (W)	130.2 \pm 11.7	137.3 \pm 11.7	133.8 \pm 13.4

*Significant gender difference ($p < 0.05$).

**Note negative value reflects a greater ROM.

Correlation Results

Figures 1-10 display the correlation results. For each figure, r and r^2 are shown in the top right corner.

Figures 1 and 2 show the relationship between passive hip flexion (degrees) and CMJH (cm) and PPO (W/kg LBM). There was a significant, negative correlation between CMJH and hip flexion, such that a higher ROM was associated with a lower CMJH. However, PPO (corrected for LBM) was not significantly correlated with hip flexion.

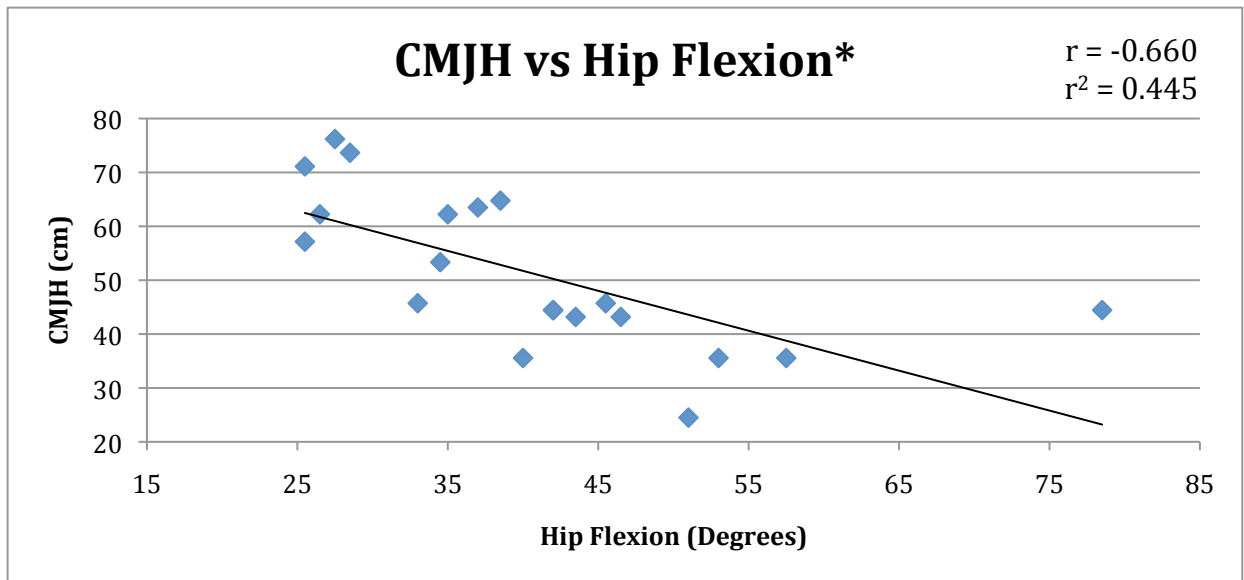


Figure 1. Countermovement jump height and hip flexion. *Significant ($p = 0.001$).

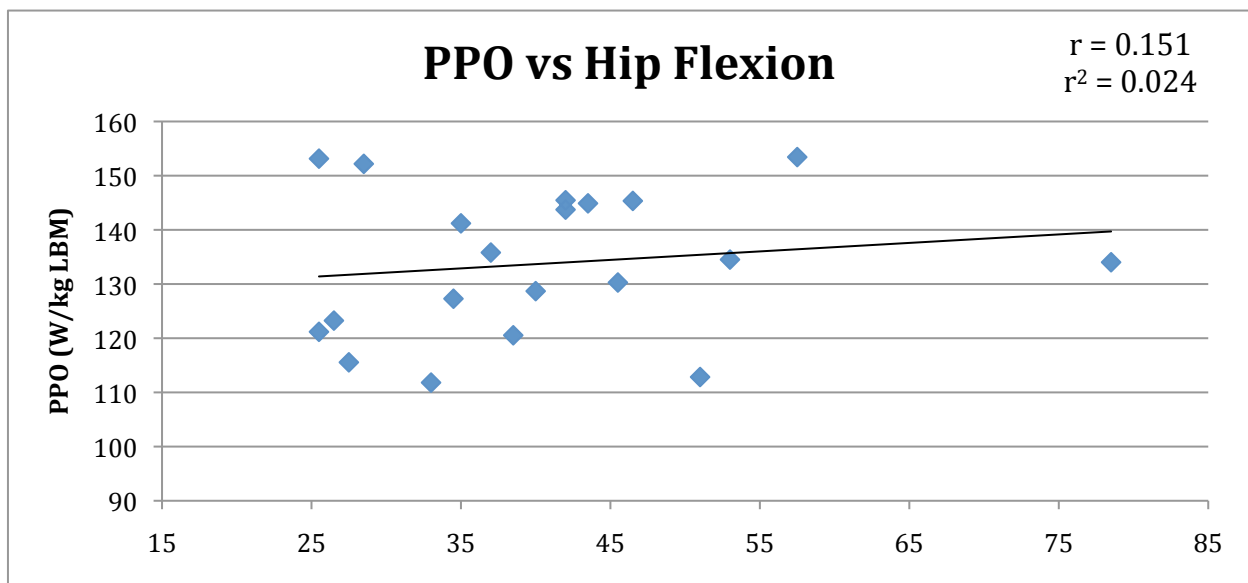


Figure 2. Peak power output and hip flexion. Not significant ($p = 0.526$).

Figures 3 and 4 show the relationship between passive hip extension (degrees) and CMJH (cm) and PPO (W/ kg LBM). There was a significant, negative correlation between hip extension and CMJH. Hip extension was the only ROM that a negative value indicated a positive outcome since if the limb was able to drop below parallel to the torso this was measured in negative degrees. Therefore, a negative value refers to an increased ROM and was

significantly associated with greater CMJH. However, PPO (corrected for LBM) was not significantly correlated with hip extension.

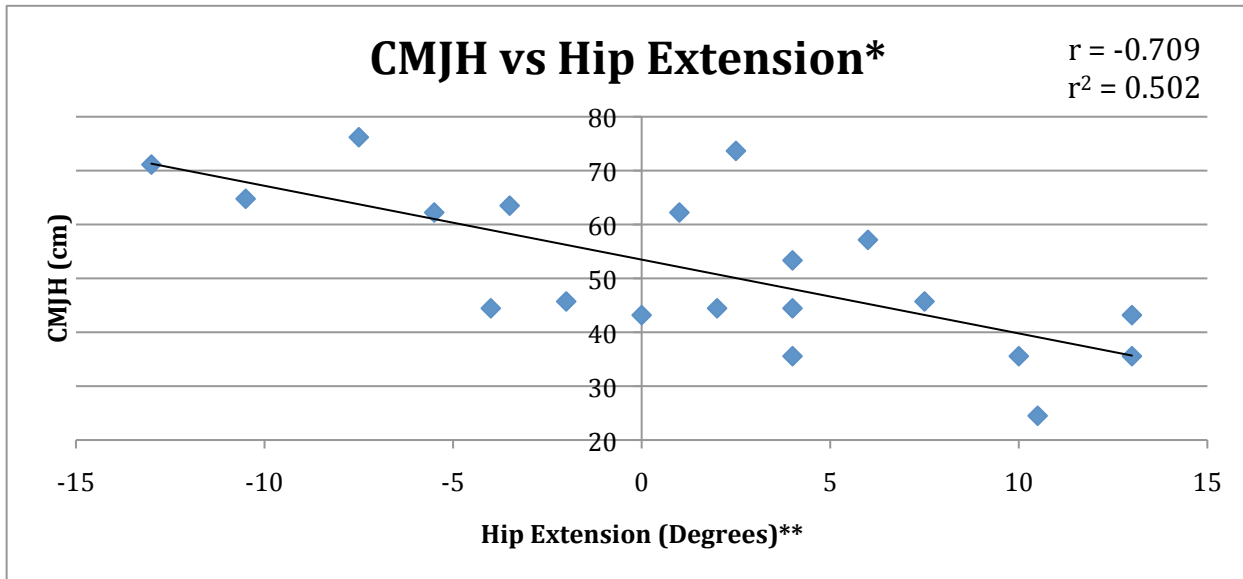


Figure 3. Countermovement jump height and hip extension. *Significant ($p = 0.001$). **Negative value indicates a greater ROM.

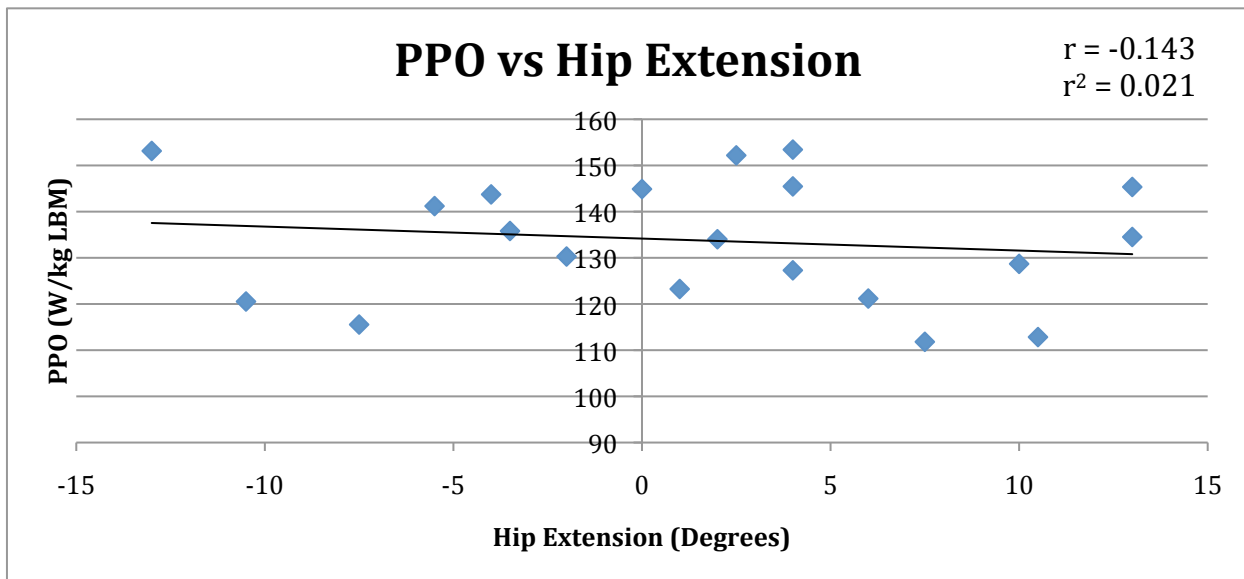


Figure 4. Peak power output and hip extension. Not significant ($p = 0.546$).

Figures 5 and 6 show the relationship between passive hip internal rotation (IR; degrees) and CMJH (cm) and PPO (W/ kg LBM). Similar to hip flexion, there was a significant negative, correlation between hip IR and CMJH. A higher ROM was associated with decreased CMJH. However, PPO (corrected for LBM) was not significantly correlated with hip IR.

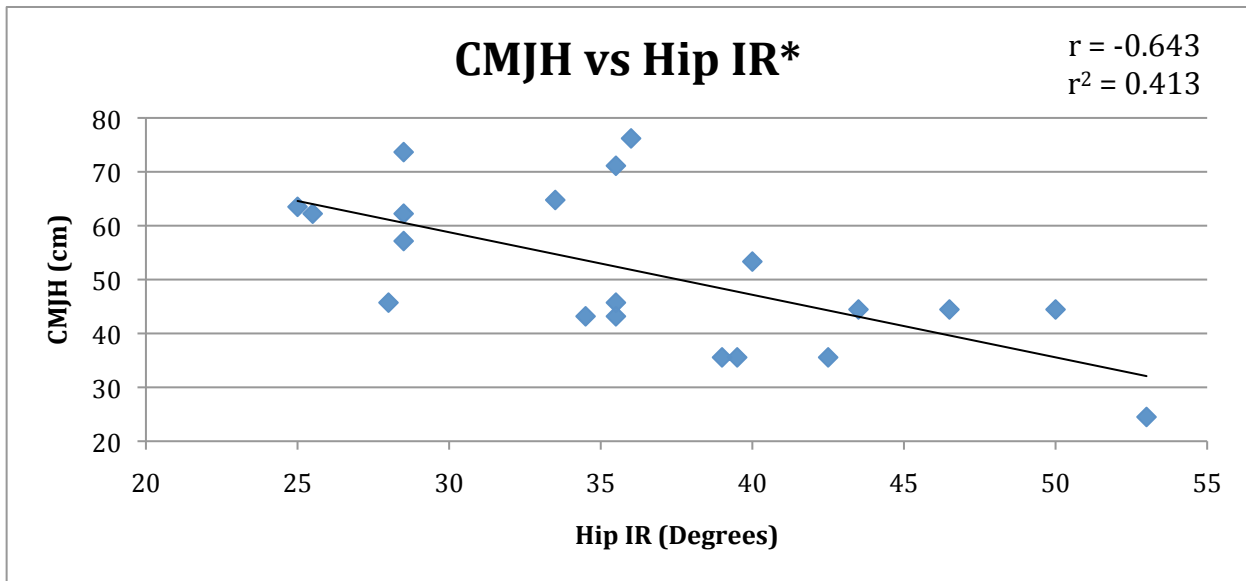


Figure 5. Countermovement jump height and hip internal rotation. *Significant ($p = 0.002$).

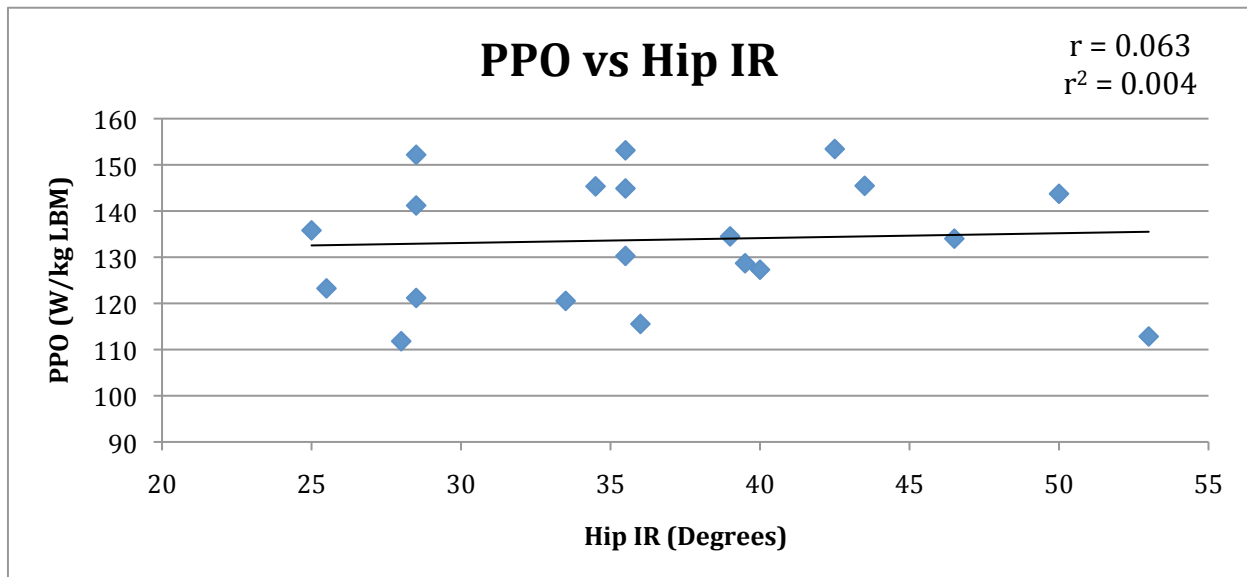


Figure 6. Peak power output and hip internal rotation. Not significant ($p = 0.793$).

Figures 7 and 8 show the relationship between passive hip external rotation (ER; degrees) and CMJH (cm) and PPO (W/ kg LBM). There was no significant correlation between hip ER and CMJH. However, hip ER was the only ROM that had a significant relationship with PPO, rather than CMJH. An increased ROM was associated with a greater PPO (corrected for LBM).

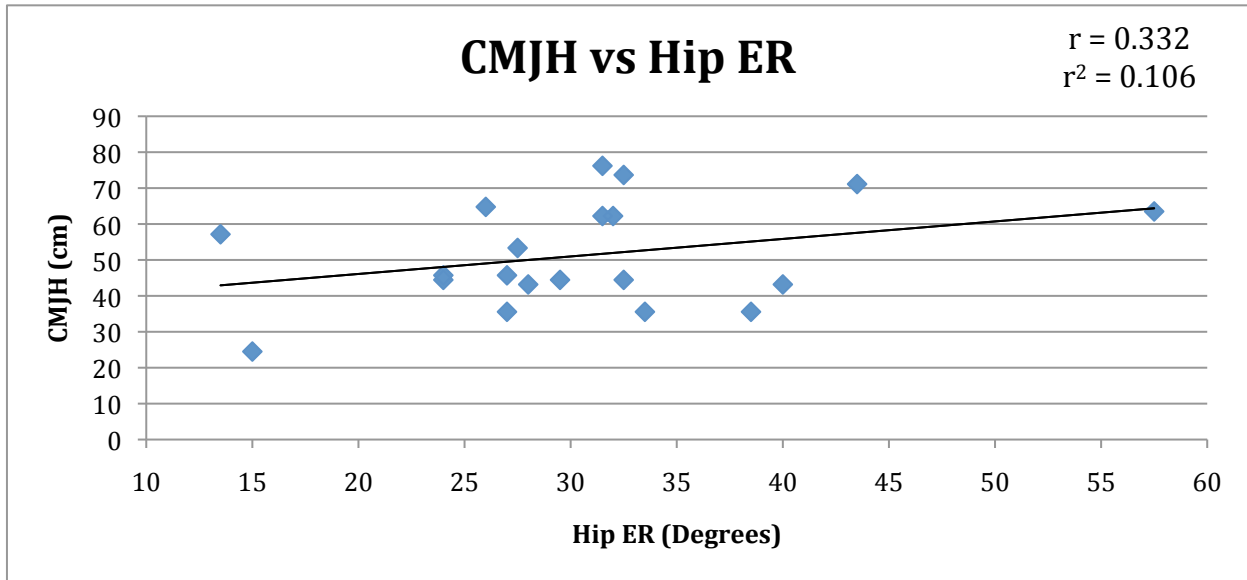


Figure 7. Countermovement jump height and hip external rotation. Not Significant ($p = 0.161$).

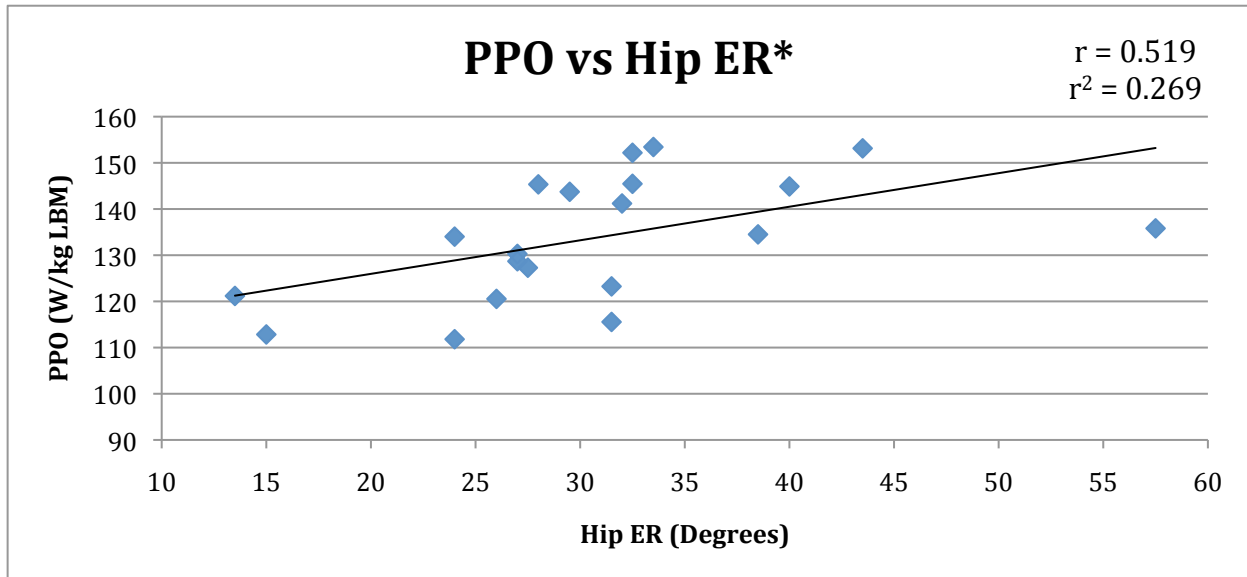


Figure 8. Peak power output and hip external rotation. *Significant ($p = 0.019$).

Gender Differences

Table 3 shows the male rankings for hip ROMs and PPO according to CMJH from highest to lowest. If subjects had an identical vertical jump height, those with a higher PPO ranking are listed first. Rankings are given 1 through 10 for the ten male subjects. Rankings that repeat for a ROM or PPO indicate an identical value in the given category. Individual differences in ROM resulted in differing CMJH and PPO for each male subject. There does not appear to be a trend such that a given ROM ranking was associated with a given CMJH ranking.

Table 3. Male (n = 10) CMJH and hip ROMs and PPO rankings.

CMJH (cm)	Hip Flexion Ranking	Hip Extension Ranking	Hip IR Ranking	Hip ER Ranking	PPO Ranking
1. 76.2	7	3	2	5	9
2. 73.7	6	7	5	3	2
3. 71.1	9	1	3	2	1
4. 64.8	1	2	4	8	8
5. 63.5	2	5	10	1	5
6. 62.2	3	4	5	4	4
7. 62.2	8	6	9	5	3
8. 57.2	9	9	5	10	7
9. 53.3	3	8	1	7	6
10. 45.7	5	10	8	9	10

Table 4 shows the female rankings for hip ROMs and PPO according to CMJH from highest to lowest. If subjects had an identical vertical jump height, those with a higher PPO ranking are listed first. Rankings that repeat for a ROM or PPO ranking indicate an identical value in the given category. Individual differences in ROM resulted in differing CMJH and PPO for each female subject. There does not appear to be a trend such that a given ROM ranking was associated with a given CMJH ranking.

Table 4. Female (n = 10) CMJH and hip ROMs and PPO rankings.

CMJH (cm)	Hip Flexion Ranking	Hip Extension Ranking	Hip IR Ranking	Hip ER Ranking	PPO Ranking
1. 45.7	6	2	8	7	8
2. 44.5	8	5	4	4	2
3. 44.5	8	1	2	5	5
4. 44.5	1	4	3	9	7
5. 43.2	5	9	9	6	3
6. 43.2	7	3	8	1	4
7. 35.6	2	6	5	3	1
8. 35.6	3	9	7	2	6
9. 35.6	10	7	6	7	9
10. 24.5	4	8	1	10	10

Figure 9 shows that male hip extension ROM had a significant relationship ($p < 0.05$) with CMJH. However, female subjects did not show any significant relationships ($p \geq 0.05$) between any ROM, and CMJH.

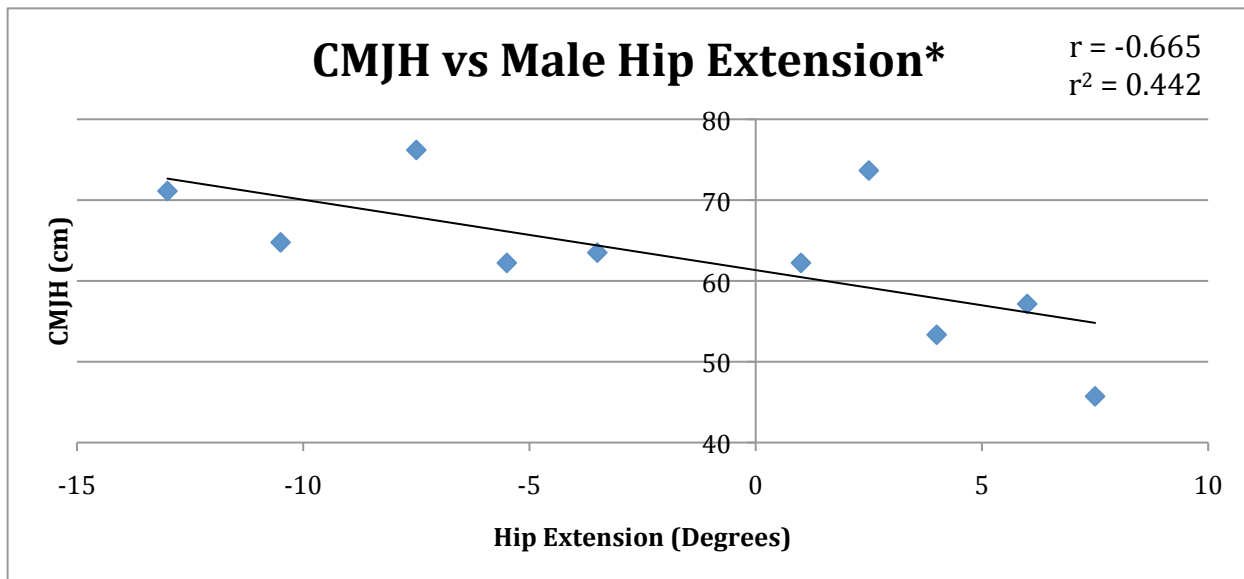


Figure 9. Countermovement jump height and male hip extension. *Significant ($p = 0.036$).

Figure 10 shows that only female hip ER ROM had a significant relationship ($p < 0.05$) with PPO (W/ kg LBM). Males did not show any significant relationships ($p \geq 0.05$) between any ROMs and PPO.

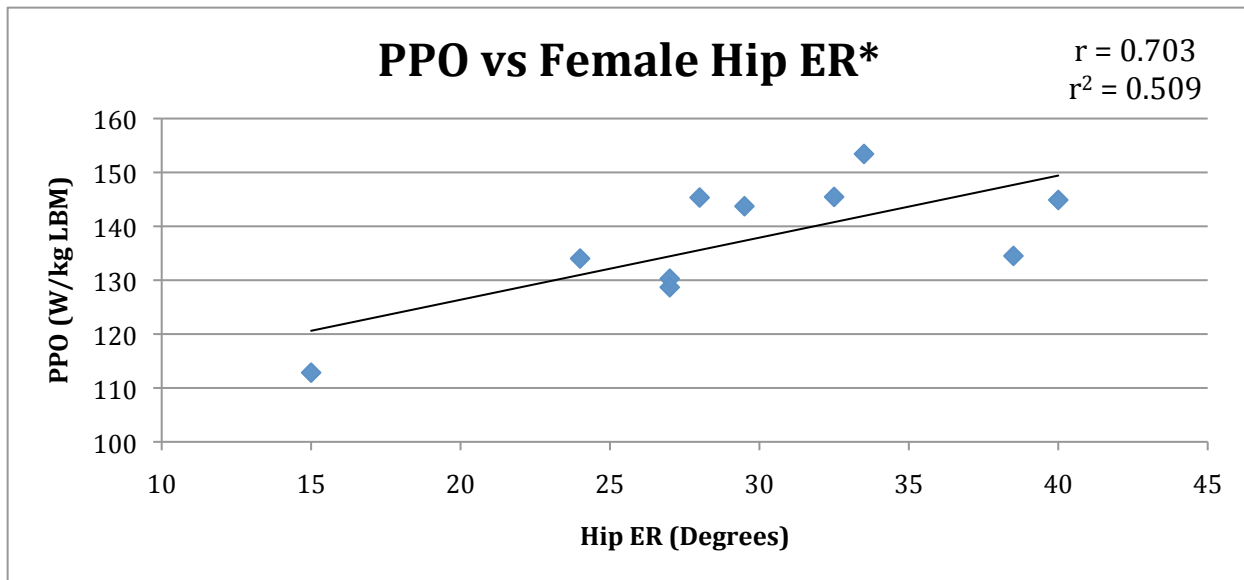


Figure 10. Peak power output and female hip external rotation. *Significant ($p = 0.021$).

Low vs. Average vs. High ROM Groups

Table 5 presents the results of the one-way ANOVA for the total sample with ROM results categorized into low, average and high groups. Because no norms were found in the literature for average ROMs, subjects were categorized into low, average and high ROM groups based on the total sample statistics. All ROMs that fell within one standard deviation (SD) of the mean for a given ROM were classified in the average group; those that fell below the SD were classified into the low group; those that were greater than the SD were classified into the high group. The means represent the average for each group, whereas the SD represent the criteria for the high and low ROMs. None of the group differences were significant ($p \geq 0.05$). The results suggest that there is no ideal ROM when looking at low, average and high.

Table 5. CMJH and PPO for low, average and high ROM groups.

Range of Motion	Total Sample Mean (n=20)	Total Sample Standard Deviation Range (±)	Low Sample Mean CMJH (cm)	Average Sample Mean CMJH (cm)	High Sample Mean CMJH (cm)	Low Sample PPO (W/kg LBM)	Average Sample PPO (W/kg LBM)	High Sample PPO (W/kg LBM)
Hip Flexion (°)	40.6	27.6 – 53.5	64.1	48.4	57.6	137.8	132.7	134.0
Hip Extension (°)	1.6	-5.9 – 9.0	56.5	51.6	45.4	129.7	135.7	130.3
Hip IR (°)	36.4	28.5 – 44.4	53.0	53.2	40.8	123.6	136.7	130.2
Hip ER (°)	30.7	21.1 – 40.3	40.9	53.5	47.4	117.0	134.5	144.5

No significant difference between groups ($p \geq 0.05$).

Discussion

The purpose of this study was to determine if passive hip range of motion (ROM) plays a role in countermovement jump height (CMJH) and peak power output (PPO). Flexion, extension, internal rotation (IR) and external rotation (ER) were measured on both hips and then averaged. CMJH (cm) was measured using a Vertec vertical jump system. PPO was measured in watts normalized for lean body mass (W/kg LBM).

It was hypothesized that passive hip ROM would have a significant relationship with both CMJH and PPO. The results showed a significant negative correlation between passive hip flexion, extension and IR with CMJH for the total sample. However, hip ER was the only ROM that had a significant correlation with PPO for the total sample. Thus, hypothesis one was partially supported. When separated by gender, male hip extension was the only ROM that had a significant negative relationship with CMJH, female hip ER was the only ROM that had a significant relationship with PPO. It was further hypothesized that the average value for each

passive hip ROM would allow for the highest jump and power output. However, there were no significant differences between the low, average and high ROM groups for either CMJH or PPO. Thus, the second hypothesis was rejected.

The literature suggests that increased hip extension is a primary component of developing power in the lower body (4,8,21,25). Differences in the ability to develop and produce power can mean the difference for competing at a higher level (3,7,10,15,17). It was hypothesized that there would be a correlation between hip extension and CMJH and PPO. There was a significant correlation between hip extension and CMJH, but not PPO. This means that greater hip extension was associated with higher CMJH. Subjects with a greater average hip extension ROM exhibited some of the highest CMJH values. There are many possible reasons for this. For the musculature of the posterior hip girdle to contract fully and forcefully, the opposing muscles on the anterior portion of the hip must relax in an agonist vs. antagonist fashion (4). An increased passive hip extension is achieved when the muscles on the anterior pelvic girdle are more lax and thus, allow the limb to extend further. If an individual is unable to fully extend at the hip, it may alter their jumping ability due to body positioning.

Hip flexion was found to have a significant negative correlation with CMJH, but was not significantly correlated with PPO. Unlike hip extension, an increased ROM of hip flexion related to a decrease in CMJH. Whereas the subject with the greatest hip extension had the third highest CMJH of the 20 subjects, the one with the greatest hip flexion had the 12th highest CMJH. These results could be due to a variety of factors. The CMJ utilizes the stretch shortening cycle (SSC) (4,10,20,21). The fact that passive hip flexion reflects the ability of the muscles on the posterior portion of the hip to stretch may impact their ability to contract rapidly. If these muscles are more lax, one might not be able to properly recruit them quickly as when

performing the CMJ. In addition, resting length of the posterior hip muscles may be altered due to hip positioning, and thus cause a change in the potential for cross-bridge interaction and a reduced power capability (4).

Hip IR also had a significant negative relationship with CMJH. As with hip flexion, an increased ROM in hip IR related to a decreased CMJH. The individual with the greatest hip IR (53°) of the 20 subjects had the lowest CMJH (24.5 cm), as well as the lowest PPO (112.8 W/kg LBM). The subject with the lowest ROM (25°) had the 5th highest CMJH (63.5 cm) and 9th highest PPO (135.8 W/kg LBM). As with hip flexion, hip IR is achieved by rotating the head of the femur and stretching the muscles of the posterior hip. This again may mean that there is a change in resting muscle length and decreased power capabilities (4).

A recent study assessing discrepancies between passive flexion and IR on either limb found a significant correlation ($r = -0.69$) associated with small differences in IR at the hip ($0.62^\circ \pm 4.97^\circ$) and broad jump length in young adult females (5). There was, however, no significant correlation between passive flexion and IR discrepancies and vertical jump height for male or female subjects (5). The data in the current study support this in that discrepancies in both hip flexion and IR were not found to have a significant correlation with CMJH or PPO.

Due to the differences in CMJH between males and females, rankings were examined separately by gender. Three males had a discrepancy of only 1° for both limbs in hip flexion. Of the 10 male subjects, these males had CMJH and PPO of 53.3 cm and 127.3 W, 76.2 cm and 115.6 W, and 71.1 cm and 153.1 W respectively. The two males with largest discrepancy (13°) had CMJH and PPO of 62.2 cm and 123.3 W and 64.8 cm and 120.5 W, respectively. The females showed similar results. The female with the greatest CMJH had a discrepancy of 5° while the subject with the lowest CMJH only had a discrepancy of 4° . A second subject had a

discrepancy of 5° and had the highest PPO (corrected for LBM) for the entire sample while the same subject with 4° of difference had the lowest PPO of the entire sample. The female who had the largest discrepancy between limbs for hip flexion had the second highest PPO out of the 10 subjects. Hip IR also showed similar findings. Two male subjects with an IR discrepancy of 1° ranked 8th CMJH and 6th for PPO, and 4th for CMJH and 9th for PPO, respectively for the 10 male subjects. The male with the largest IR discrepancy (7°) had the 3rd highest CMJH and highest PPO. This suggests that neither passive flexion nor IR discrepancies should be used to predict PPO.

In addition to the discrepancies between limbs, individuals with the same range of motion in a given movement showed different abilities to express power. Two female subjects had the same IR measurement of 35.5° (8th of 10), with respective PPO rankings of 8th and 4th out of 10 female subjects. Three male subjects all had the same IR measurement of 28.5° (5th of 10) with PPO rankings of 2nd, 4th and 7th out of 10 male subjects. This highlights the individual variability for ROMs and PPO.

The only ROM that had a significant correlation with PPO was hip ER. For the head of the femur to externally rotate, the muscles of the inner thigh (adductor longus and gracilis) must relax and be placed on stretch. During the vertical jump, the gluteus muscles are activated, which can lead to external rotation. If the gluteus muscles are able to contract forcefully enough, they may activate the Golgi tendon organs of the inner thigh muscles forcing them to relax (4) and allow for a greater maximal contraction and higher power output. Likewise, the muscle spindles may also come into play during the CMJ. During the countermovement phase of the jump, the hip is placed in a flexed position, stretching the posterior muscles of the pelvis. As these muscles stretch, the muscle spindles sense this and may cause an increased contraction (4).

Lastly, an alteration in the resting length of a particular muscle or muscle group may also be a factor in the ability to fully express power.

As a trainer for athletes, flexibility should be a part of any program. However, to what extent should be determined based on the sport or position of the athlete. Whereas some athletes may need an increased ROM, like a gymnast, to allow them to perform specific movements, others may benefit from a certain degree of muscle stiffness such as a baseball pitcher. Correcting imbalances in hip ROM may allow for a wider variety of exercises and movements in a training program while also having a benefit that translates directly to their sport.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Passive hip extension, flexion and internal rotation ROMs were found to have significant correlations to countermovement jump height. While hip extension was the only ROM that correlated to an increased jump height, hip flexion and internal rotation correlated to a decreased jump height. Passive hip external rotation was the only ROM found to have a significant correlation with peak power output corrected for lean mass. Increased external rotation was related to an increase in peak power output. There was no optimal range of motion found when comparing low, average and high ROM groups for countermovement jump height or peak power output.

Limitations

There were four main limitations to this study. First, power was predicted through the use of the Harman power equation that has an error of ± 603 W. If a force plate were available it would allow for a more accurate measure of peak power output. Also, it would negate the effect of jump technique on the Vertec jump system scores. Although proper jump technique was

demonstrated and three attempts were given to reach a maximal jump height, it is possible that an individual would be able to display more accurate power from the use of a force plate.

Secondly, the sample consisted of individuals who did not compete in power sports that utilize jumping or rapid power production. Power athletes may be more highly trained to produce power, despite their range of motion in a particular movement. Trained athletes also would have likely scored higher on the CMJ test, as it is a common test used in athletes (1,3,4,10,15,17).

The third limitation was the size of the sample (20 total; 10 males and 10 females). Although the data produced significant results for three of the four ROMs in the correlational analysis, the sample size may have limited the ability to detect group differences (low, average and high ROMs).

The last limitation that should be noted is that the sample had a rather limited age (23.5 ± 3.0 years), which excluded high school aged individuals, as well as adults over the age of 30 years.

Future Research

The results of this study suggest possible routes for further research. First, power was estimated from the vertical jump using the Harman power equation, whereas a force plate would provide a more accurate measure of power output. Given that there is a variance of ± 603 W for the Harman equation, there is room for error. Although the PPO values used were corrected for lean body mass, the Harman equation uses only body mass. The male values from the highest power output (9886.8 W) compared to the lowest power output (7208.2 W) showed a difference of 2678.6 W. Even with the ± 603 W variance applied, these values would not overlap and it can be said with confidence that there was a significant difference in power output between the male subjects. The females, however, had a smaller range of values for power output with a high of

6695.1 W and a low of 5428.4 W, for a difference of only 1266.7 W. Given the error of ± 603 W in either direction, there is a potential that values could actually have a difference of only 60 W, which is very small. If a force plate is available, future research should be conducted so that a more accurate measure of power output can be made.

A second topic for future research is to determine if there is an optimal hip range of motion for CMJ and PPO. Although this study did not find a given set of values that resulted in the greatest jump height or power output, a larger sample or varying age groups may elicit different results. The correlation between passive hip extension, flexion and internal rotation show that these play a role, but to what extent must be further examined.

Lastly, research should be conducted on how improvements in passive range of motion may increase vertical jump height and peak power output. It was reported that improvements in hip extension did not alter some functional tests, including active hip extension, forward lunge, twist and reach and use of an elliptical trainer (25), however, vertical jump and power output were not measured. Improvements in range of motion may allow stabilizer muscles of the lower body to function properly and allow for a more direct application of force.

Conclusion

Research has shown that flexibility and range of motion can play a role in various aspects of performance and strength. This study found significant negative correlations between passive hip range of motion and vertical jump height. The ability for the hip joint to extend, flex and rotate properly and through a varying range of motion had a significant relationship with the ability to reach a maximum jump height. The negative correlation with hip extension shows that an increased range of motion may be more beneficial. As for hip flexion and internal rotation, the negative correlation shows that an increased range of motion may be associated with a

reduced vertical jump height. External rotation was the only range of motion that showed a significant correlation with peak power output corrected for lean body mass. There was also no optimal range of motion that resulted in the greatest jump height or power output in any of the movements tested. Individual differences in the passive hip flexion, extension, internal rotation and external rotation may combine for a unique ability to express power in the vertical jump.

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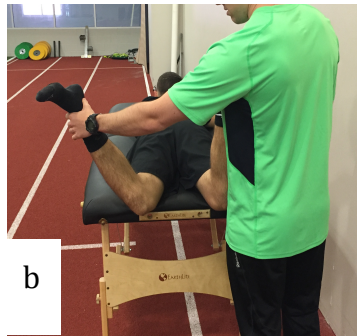
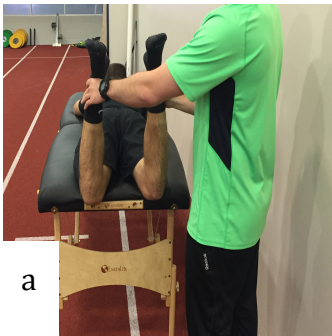
APPENDICES

APPENDIX A

Passive Hip Range of Motion Testing Procedures



1. Hip extension ROM testing: Modified Thomas Test position used to measure hip extension. Right leg is being lowered to full extension while controlling ab/adduction (24).



2. Hip internal/external hip ROM testing: a) Quiet Lying Position used as 0°. b) Unilateral internal hip rotation (left leg shown). c) Unilateral hip external rotation (left leg shown) (24).



3. Hip flexion ROM testing: Test as described by Starkey et al. Subject lies in a supine position with both legs extended. While applying slight pressure proximal to the knee joint, researcher flexes the hip by lifting the tested limb's foot off the table. Once the opposite limb rises off the table or there is hip rotation, a measurement is taken with the goniometer.

APPENDIX B

AHA/ACSM Health/Fitness Pre-participation Screening Questionnaire

Name _____

Date _____

AHA/ACSM Pre-participation Screening Questionnaire

Assess Your Health Needs by Marking all *true* statements

History

You have had:

- A heart attack
- Heart Surgery
- Cardiac Catheterization
- Coronary angioplasty (PTCA)
- Pacemaker/implantable cardiac
- Defibrillator/rhythm disturbance
- Heart valve disease
- Heart failure
- Heart transplantation
- Congenital heart disease

Recommendations:

If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Other health issues:

- You have musculoskeletal problems. (*Specify on back*)*
- You have concerns about the safety of exercise. (*Specify on back*)*
- You take prescription medication (s). (*specify on back*)*
- You are pregnant

Symptoms

- You experience chest discomfort with exertion.
- You experience unreasonable breathlessness.
- You experience dizziness, fainting, blackouts
- You take heart medications.

Cardiovascular risk factors

- You are a man older than 45 years.
- You are a woman older than 55 years or you have had a hysterectomy or you are postmenopausal.
- You smoke.
- Your blood pressure is greater than 140/90 mm Hg.
- You don't know your blood pressure.
- You take blood pressure medication.
- You don't know your cholesterol level.
- You have a blood cholesterol >240 mg/dl.
- You have a blood relative who had a heart attack before age 55 (*father/brother*) or 65 (*mother/sister*).
- You are diabetic or take medicine to control your blood sugar.
- You are physically inactive (*i.e., you get less than 30 minutes of physical activity on at least 3 days/week*).
- You are more than 20 pounds overweight.
- None of the above is true.

If you marked two or more of the statements in this section, you should consult your healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified staff to guide your exercise program.

You should be able to exercise safely without consultation of your healthcare provider in almost any facility that meets your needs.

- Proceed with test if musculoskeletal problems are minor, concerns about safety of exercise are normal, and prescription medications are not for cardiac, pulmonary, or metabolic disease.

Risk Status (Low, Moderate, High): _____

APPENDIX C

Informed Consent
Relationship of Passive Hip Range of Motion to
Counter Movement Jump Height and Peak Power Output

Introduction

My name is Jacob Hoopingarner and I am conducting my Master's Thesis in the Human Performance Laboratory at Cleveland State University under the supervision of Dr. Kathleen Little. The purpose of my thesis is to determine the relationship between hip range of motion and vertical jump height and peak power output. Based on the results, exercise specialists will be able to identify individuals that need to work on flexibility and those that do not.

Procedures:

All testing will be done in a single session that will last approximately 30 minutes. You will have your body fat measured using a device called the BodPod. Next, you will warm-up by ride a stationary bike for five minutes at a low intensity. Then, four hip range of motion measurements will be taken. This will be done by having the researcher move your legs through various positions and taking measurements with a device called a goniometer. Then you will perform a vertical jump test using a Vertec vertical jump measuring system.

Risks and Discomforts:

Risks of this tests are minimal and do not exceed those of a standard exercise session. This can include possible muscle strain and soreness from vertical jump testing. Other potential risks during exercise include abnormal heart rate/rhythm and/or blood pressure, fainting, and in rare instances, heart attack, stroke or death.

Every effort will be made to minimize potential risks by including a warm-up prior to exercise testing. In addition, you must be classified as "Low Risk" according to the AHA/ASCM Health Screening Questionnaire. The CSU Human Performance Laboratory has standard emergency procedures posted and an Automatic External Defibrillator (AED) mounted on the wall. All laboratory personnel are certified in CPR/First Aid.

Benefits:

The results of this research will help exercise professionals in the design of flexibility and exercise prescription for maximal vertical jump height. The benefits to you is that the results may give you an idea as to whether or not you need to improve hip flexibility.

Confidentiality:

To ensure all information is confidential, your data will be placed in a folder and stored in a secure file cabinet in the CSU Human Performance Laboratory where only the researchers will have access. Your name will not be included in any publications of this research. However, any data obtained from this study may be used for statistical or scientific purposes with your right of privacy retained.

Participation:

I understand that participation in this research study is voluntary and that I have the right to withdraw at any time with no consequences.

I understand that if I have any questions about my rights as a research subject I can contact the Cleveland State University Institutional Review Board at (216) 687-3630.

If I have any questions about the procedures, I can contact Dr. Kathleen Little at (216) 687-4877 or k.d.little@csuohio.edu or Jake Hoopingarner at jakehoopingarner@gmail.com or (440) 897-5100

Subject Acknowledgment:

I attest that I am 18 years of age or older and agree to participate in this study. I have been given a copy of this consent form.

Participant Signature: _____ Date: _____

Witness Signature: _____ Date: _____

APPENDIX D

IRB Approval Letter

Mon, 18 May 2015 1:22 PM PDT

Dear Kathleen Little,

RE: IRB-FY2015-21

Relationship of Passive Hip Range of Motion to Countermovement Jump Height and Peak Power Output

The IRB has reviewed and approved your application for the above named project, under the category noted below. Approval for use of human subjects in this research is for a one-year period as noted below. If your study extends beyond this approval period, *you must contact this office to initiate an annual review of this research.*

Approval Category: Expedited 4

Approval Date: May 18, 2015

Expiration Date: May 16, 2016

By accepting this decision, you agree to notify the IRB of: (1) any additions to or changes in procedures for your study that modify the subjects' risk in any way; and (2) any events that affect that safety or well-being of subjects. Notify the IRB of any revisions to the protocol, including the addition of researchers, prior to implementation.

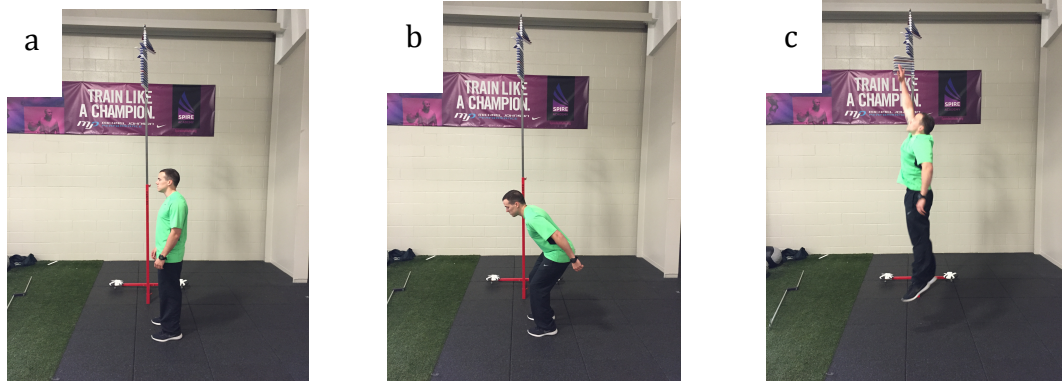
Thank you for your efforts to maintain compliance with the federal regulations for the protection of human subjects. Please let me know if you have any questions.

Sincerely,

Bernie Strong
IRB Analyst
Sponsored Programs and Research Services
[\(216\) 687-3624](tel:(216)687-3624)
b.r.strong@csuohio.edu

APPENDIX E

Countermovement Jump (CMJ) Form



Countermovement jump form: a) Start position b) Countermovement phase c) jump phase

APPENDIX F

Vertec Vertical Jump System



Vertec vertical jump system and vanes (34).